Marshall Space Flight Center

HIRAD

Calibration of Hurricane Imaging Radiometer C-Band Receivers

Sayak K. Biswas [1,2]*
Daniel J. Cecil [2]
Mark W. James [2]

(1) Universities Space Research Association
(2) NASA Marshall Space Flight Center
* presenting author: sayak.k.biswas@nasa.gov

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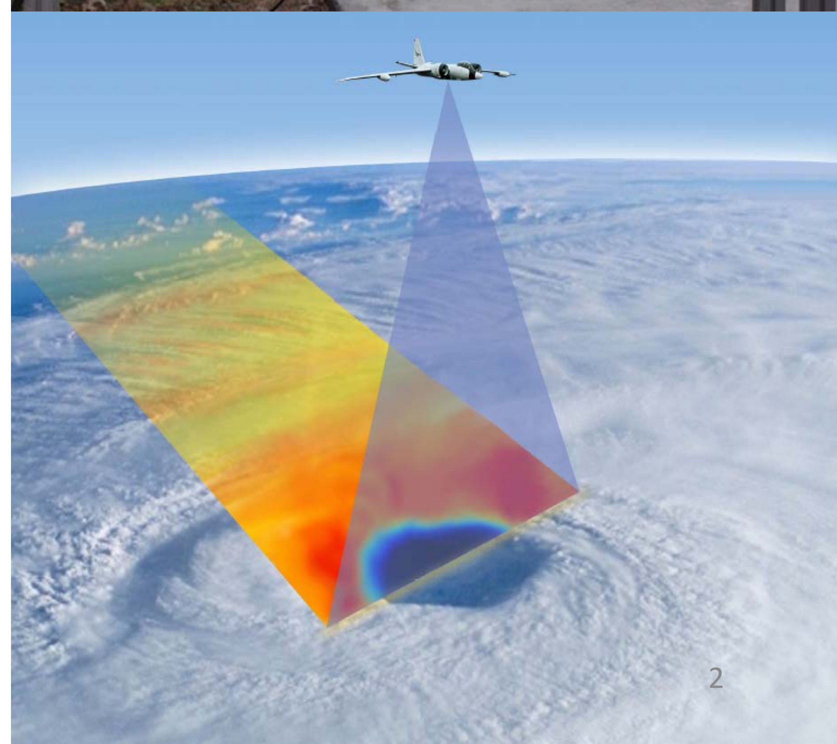
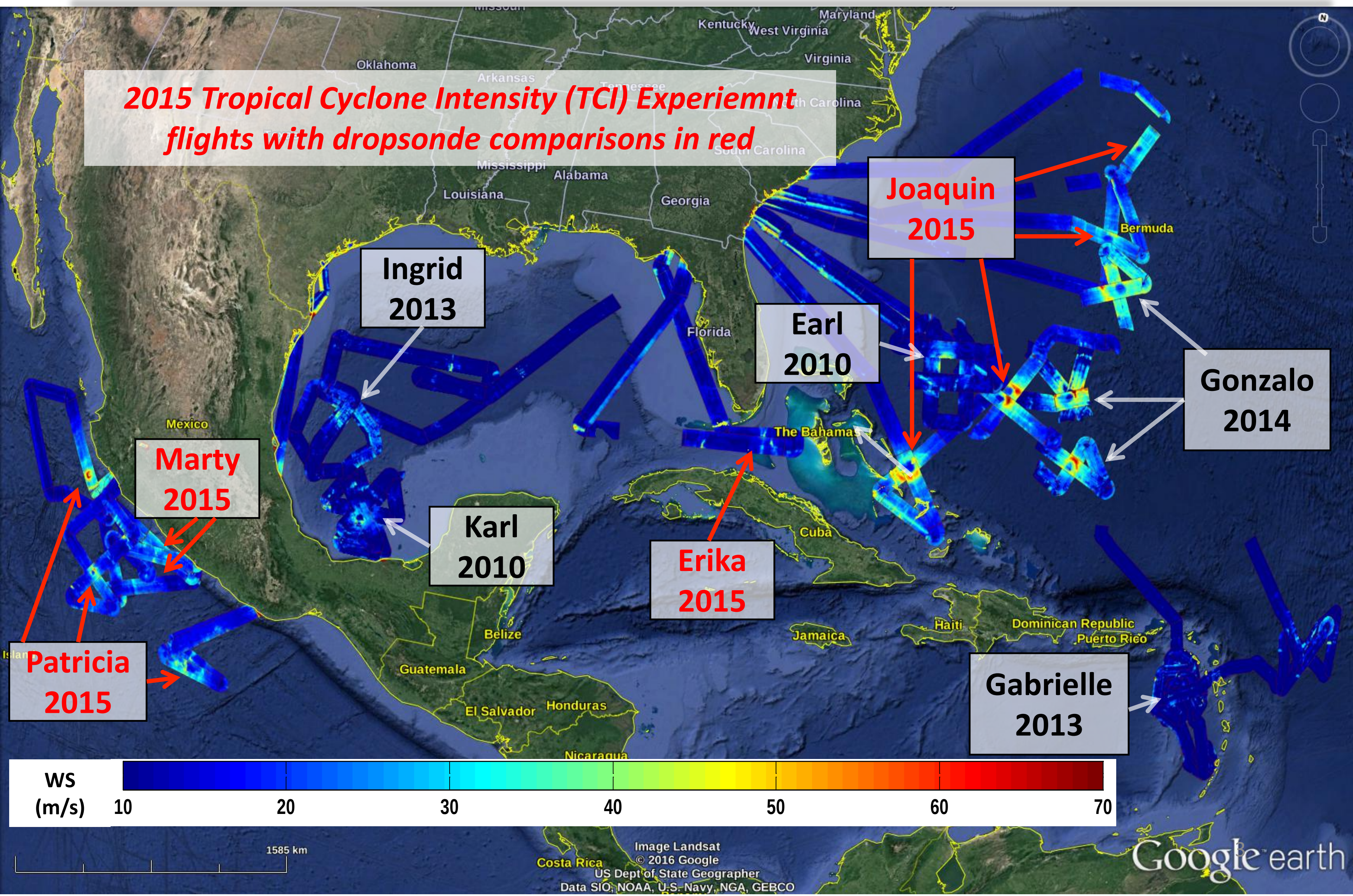
Hurricane Imaging Radiometer

- **Objectives:**
  - Map surface wind speed over wide swath (~50-60 km, for aircraft > FL600) in hurricanes
  - Provide research data for understanding hurricane structure, intensity change
  - Enable improved forecasts, warnings, decision support
- **Technical Approach:**
  - C-band multi-frequency microwave radiometer; retrieval approach similar to operational SFMR
  - Interferometric aperture synthesis in the cross-track direction to image wide swath (SFMR : nadir only measurements).
- **Future Goals:**
  - Upgrade to add wind direction
  - More robust 2nd-generation instrument(s)



HIRAD Wind Speed Retrievals, 2010-2015

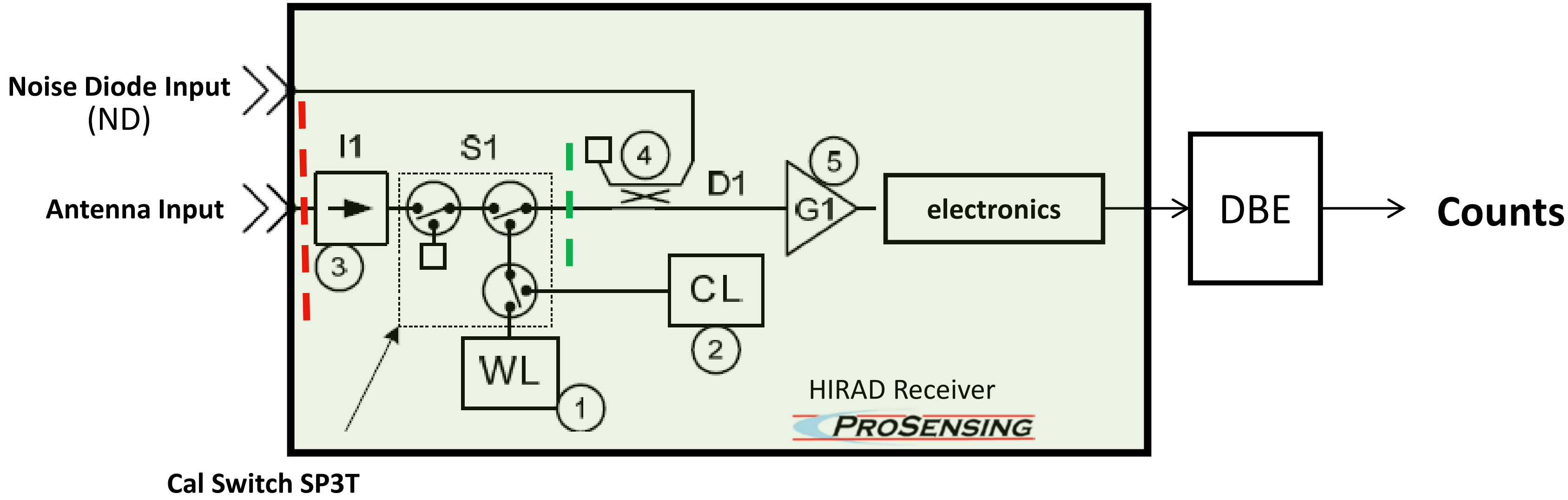


HIRAD WS Evaluation during TCI

- Tropical Cyclone Intensity (TCI) Experiment, 2015
  - Sponsored by Office of Naval Research
  - HIRAD and High Density Sounding System (HDSS) on NASA WB-57 in 2015
  - Hurricanes Joaquin, Patricia, Marty, and remnants of TS Erika
- Results (*Cecil & Biswas, 2017)
  - HIRAD surface wind speed retrievals evaluated using HDSS dropsonde intercomparison for 636 sondes, 10 flights during 2015 TCI project
  - Performance looks good across all incidence angles
  - Bias < 2 m s^{-1}; near zero for most flights
  - Estimated RMS Error ~ 4.7 ms^{-1}
    - SFMR – dropsonde RMS Difference is 3.9 ms-1 (2015 version)
- This presentation details the determination of calibration parameters for 10 HIRAD multi-frequency (4, 5, 6 & 6.6 GHz) receivers. These parameters were used to generate HIRAD TB images during TCI, 2015.

* Cecil D.J. and Biswas S.K., Hurricane Imaging Radiometer Wind Speed Retrievals and Validation Using Dropsondes, *Journal of atmospheric and oceanic technology*, 2017 (submitted)

Receiver Front-End Schematic



I1 = Input Isolator

S1 = Switch assembly generating three switching states (SP3T)

WL = Warm Load

CL = Cold Load

D1 = Directional Coupler (for coupling noise diode)

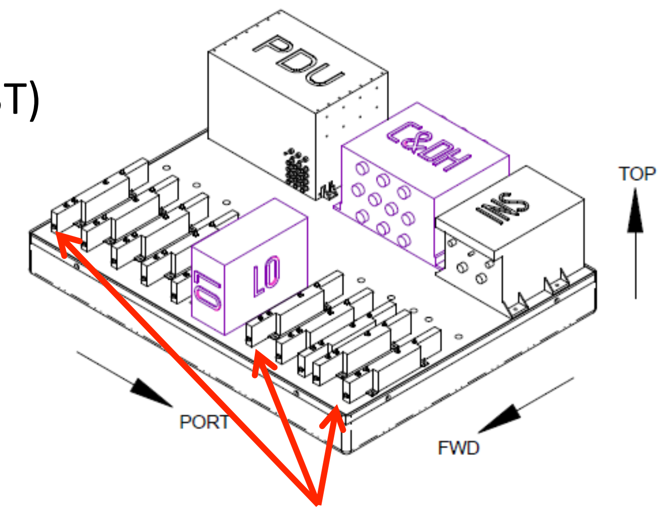
G1 = Low Noise Amplifier (LNA)

DBE = Digital Back End (housed inside C&DH)

1 through 5 are the location of RTD

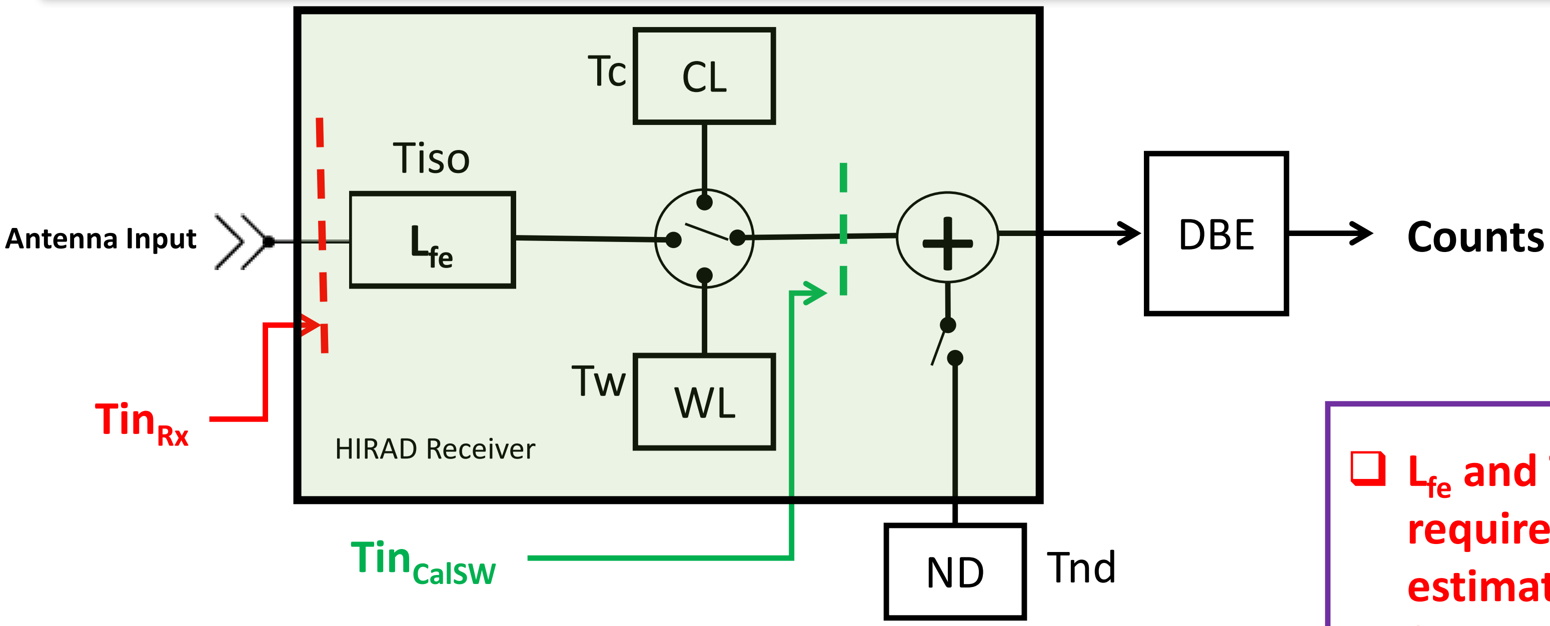
– – – – – Antenna Input Reference

– – – – – Cal Switch Output Reference



10 Receivers

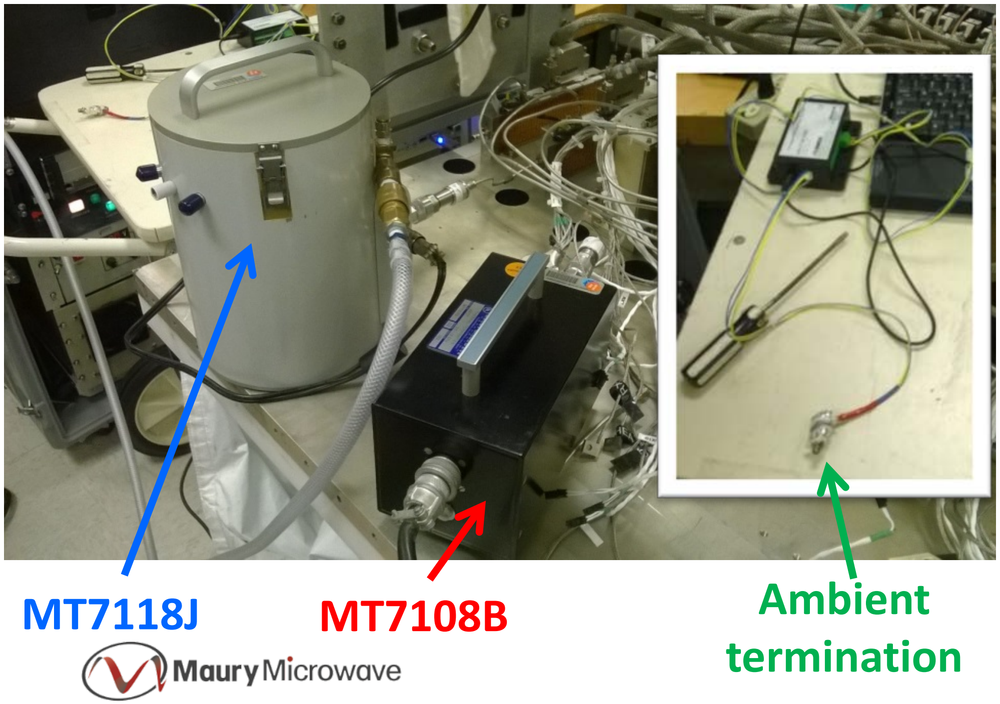
Receiver Front End Loss Model

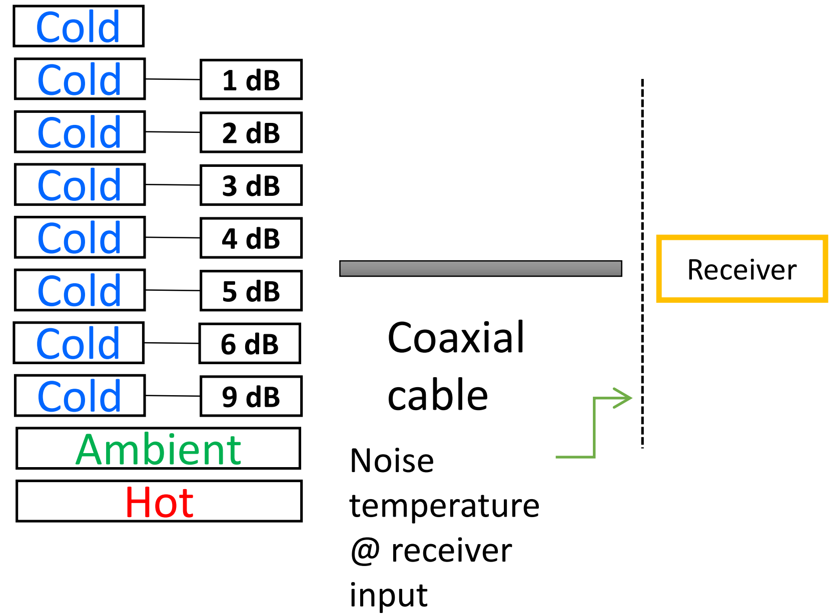


- L_{fe} : transmission coefficient of the front-end loss
- Tin_{Rx} : noise temperature referenced at the receiver input
- Tin_{CalSW} : noise temperature referenced at the switch o/p
- The Tin_{CalSW} and Tin_{Rx} are related by :
  - $Tin_{CalSW} = L_{fe} * Tin_{Rx} + (1 - L_{fe}) * Tiso$ --- (1)
  - Tiso is the physical temperature of L_{fe} (given by RTD#3)
- Tc (Tw) is cold (warm) load noise temperature and Tnd is the excess noise temperature added by the noise diode

- ❑ L_{fe} and T_c or T_{nd} are required to estimate Tin_{Rx} from measured counts.
- ❑ External noise references were used to determine these parameters in laboratory.

Laboratory Calibration Setup

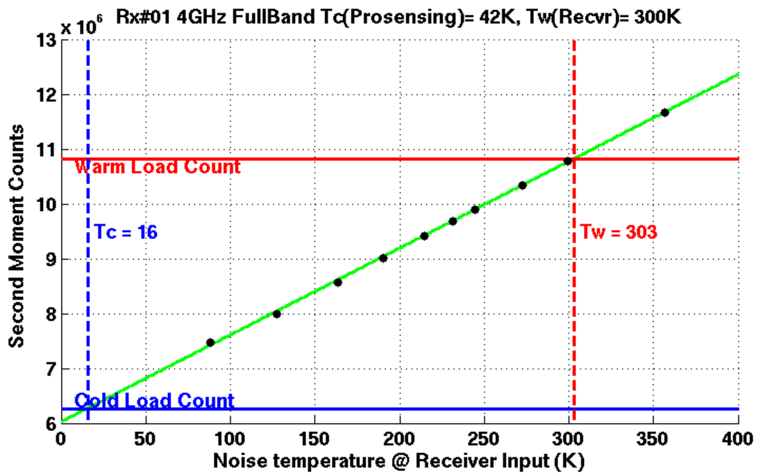




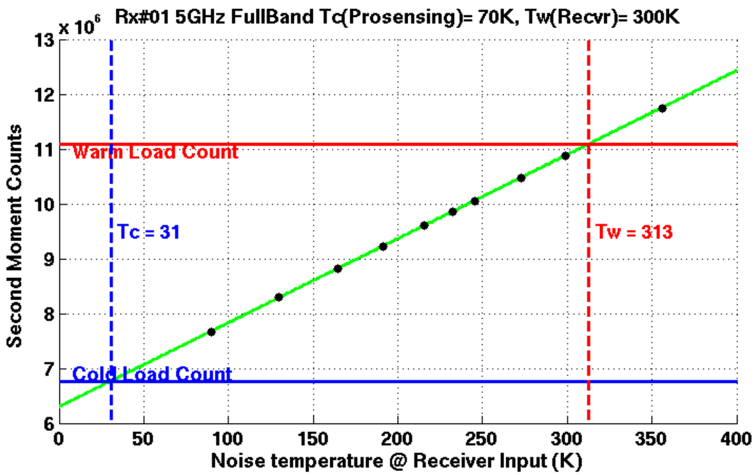
- External Calibration Reference
  - Cold Reference – 7mm Coaxial Cryogenic termination (MT7118J)
  - Hot Reference – 7mm Coaxial Thermal termination (MT7108B)
  - Ambient reference – 50 ohm RF termination (DC-20GHz), ~ - 30dB return loss.
- Cold reference output noise temperature @ HIRAD freqs: 80.6,81,81.5 and 82 K
- Ambient load temp measured using RTD data logger
- Hot load maintained @ 85.3 deg C

Receiver # 01 : Counts vs. Tin_{Rx}

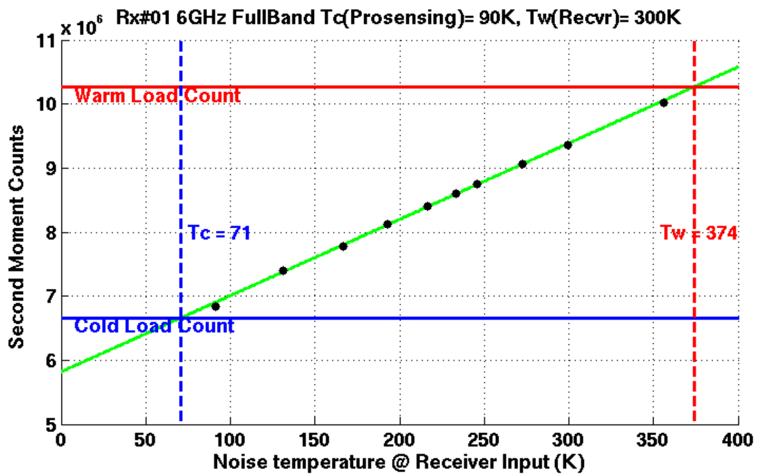
4.0 GHz



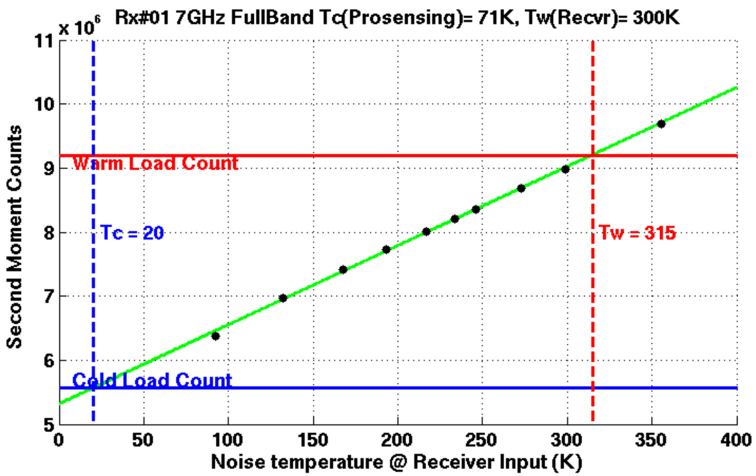
5.0 GHz



6.0 GHz

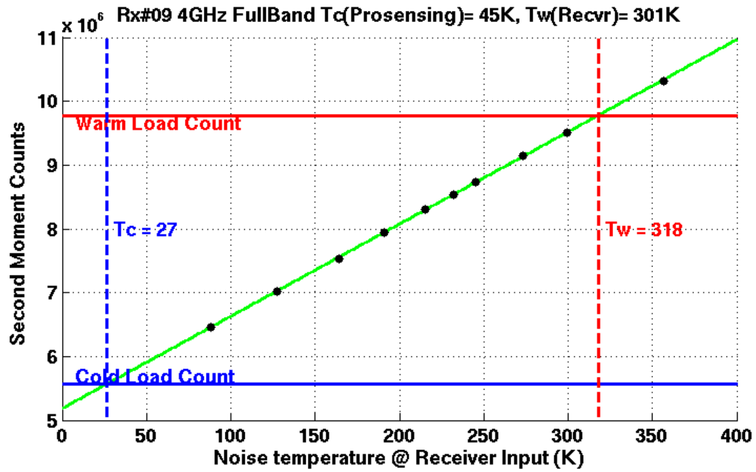


6.6 GHz

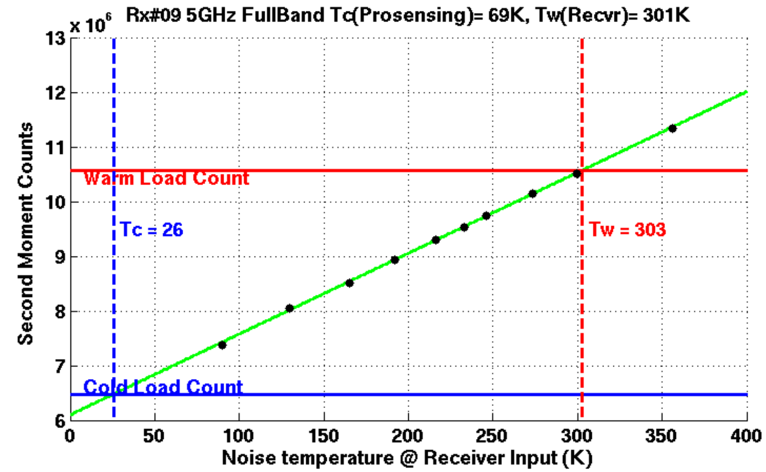


Receiver # 09 : Counts vs. Tin_{Rx}

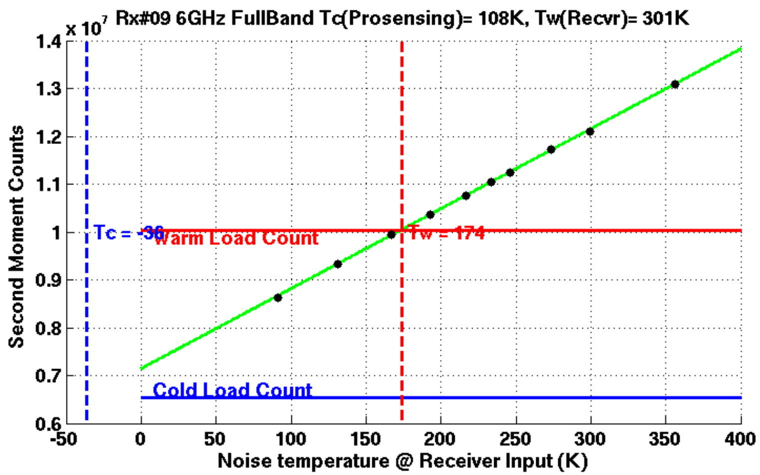
4.0 GHz



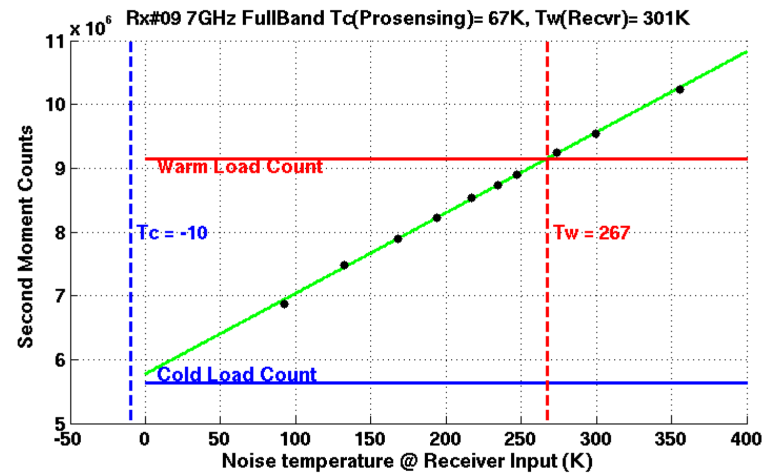
5.0 GHz



6.0 GHz

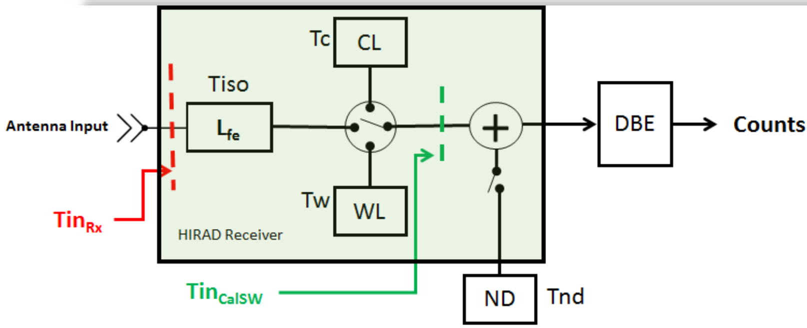


6.6 GHz

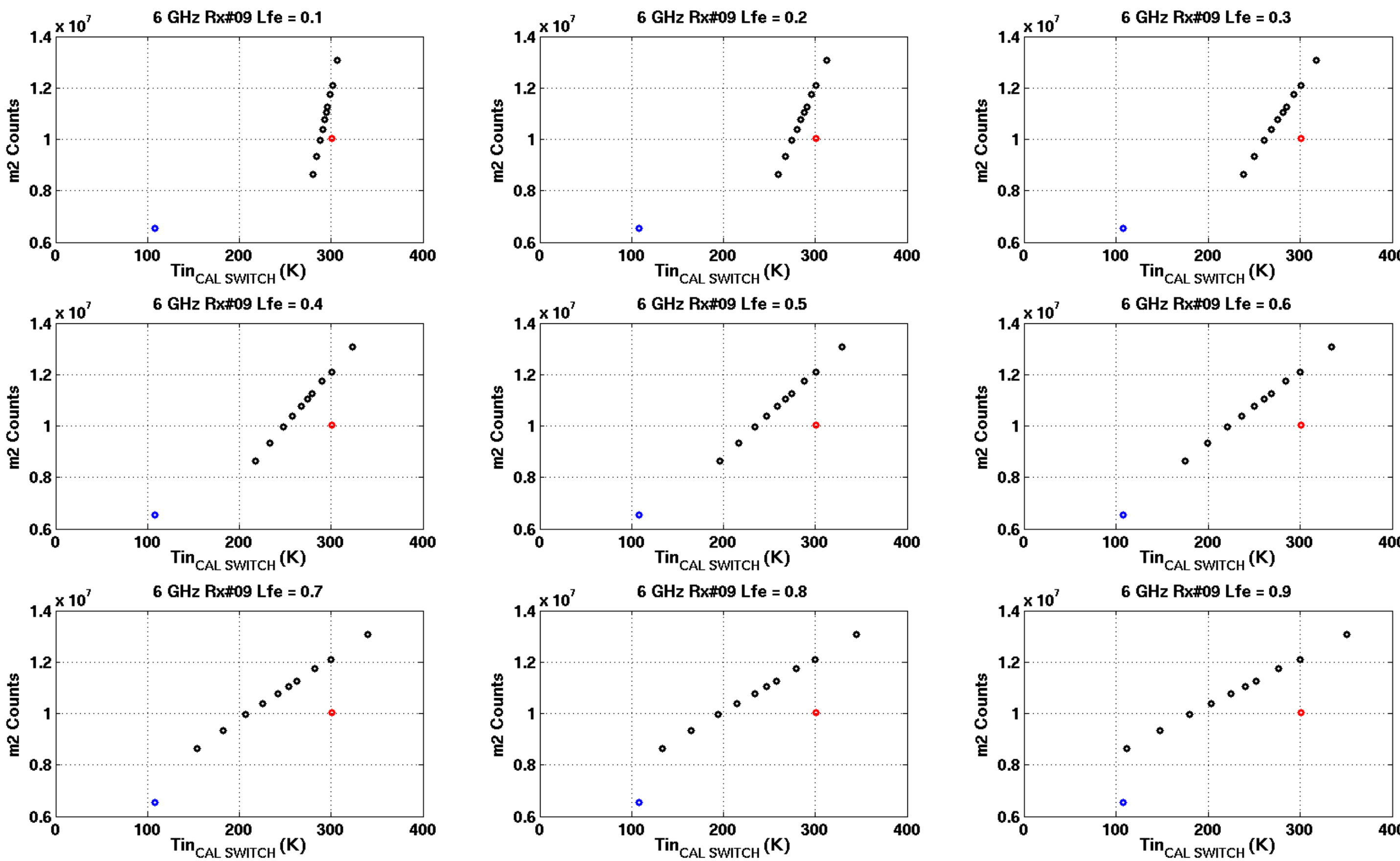


6.0 GHz Worst Case !

Effect of L_{fe} Adjustment (6 GHz, Rx#09)

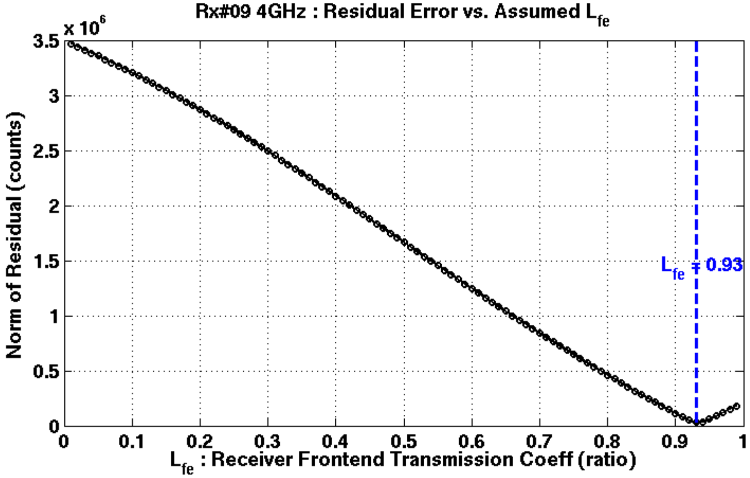


$$Tin_{CalSW} = L_{fe} * Tin_{Rx} + (1- L_{fe}) * Tiso \quad \text{--- (1)}$$

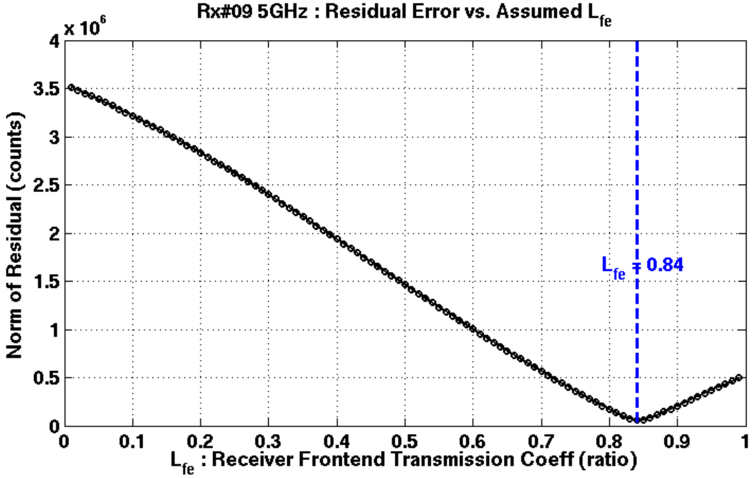


Rx#09 Best Fit Residual Error vs L_{fe}

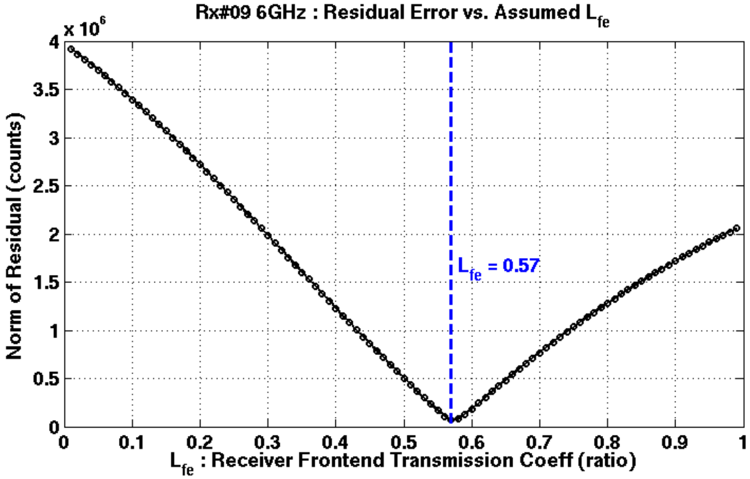
4.0 GHz



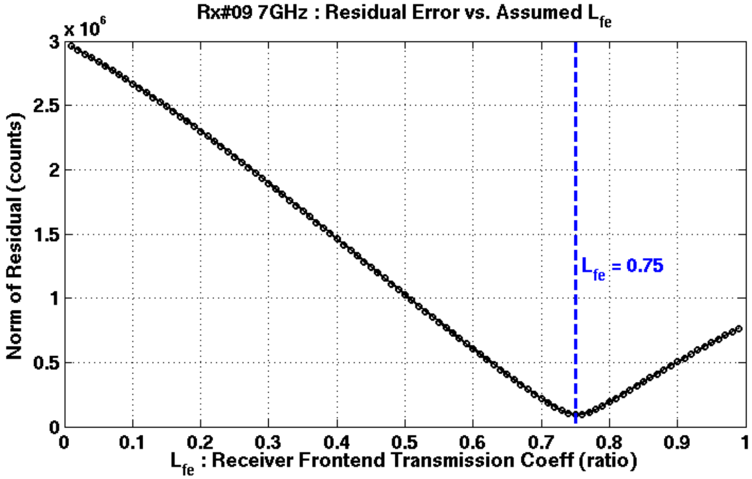
5.0 GHz



6.0 GHz

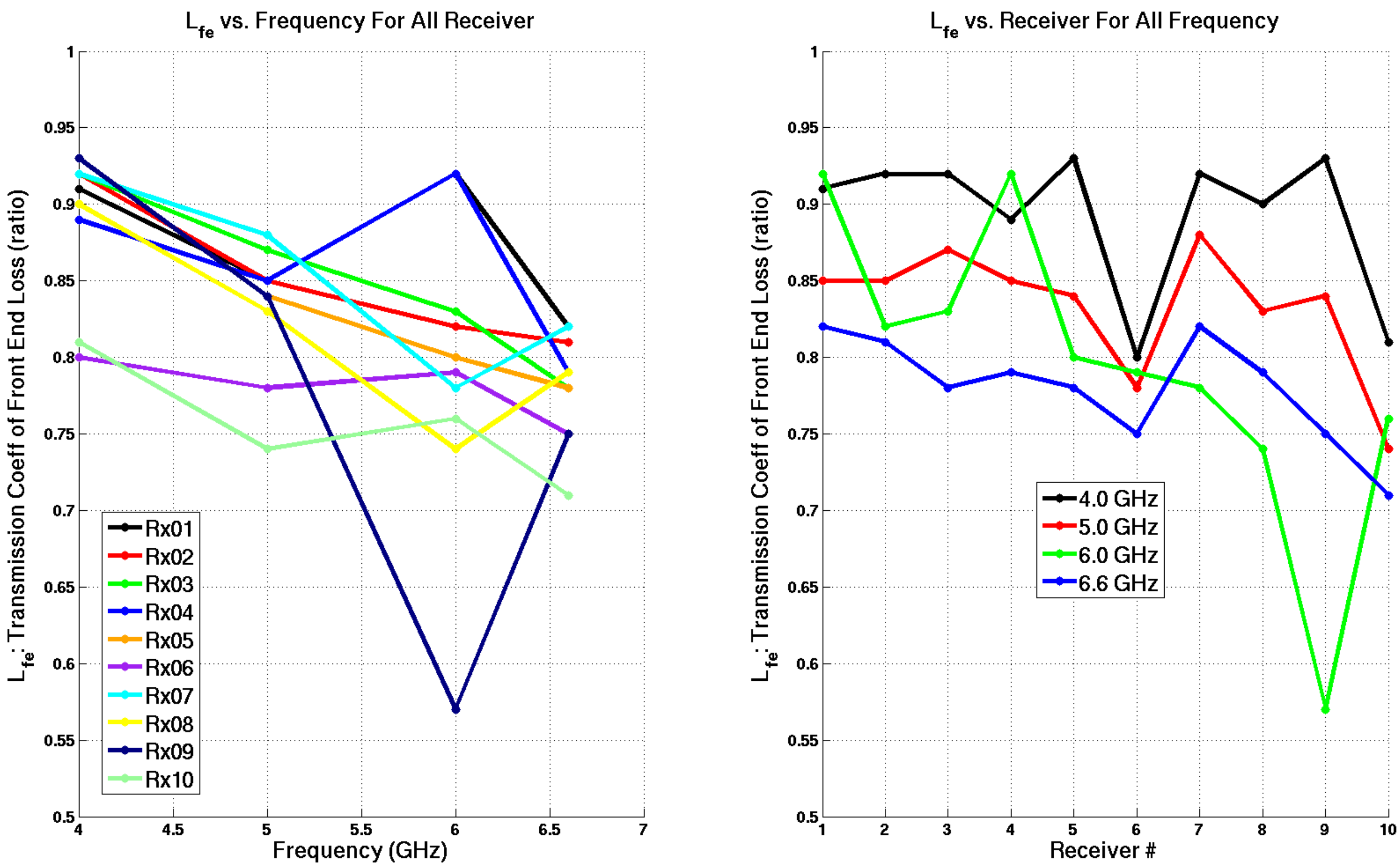


6.6 GHz



L_{fe} solution based on minimum residual error

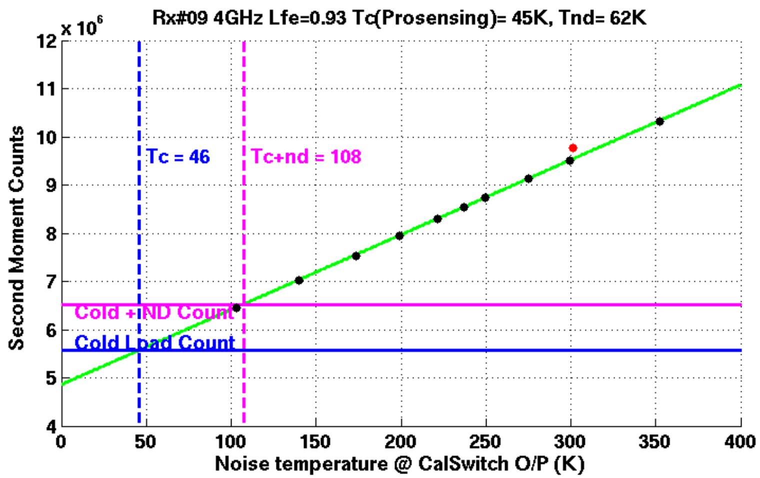
Estimated Front-end Loss (L_{fe})



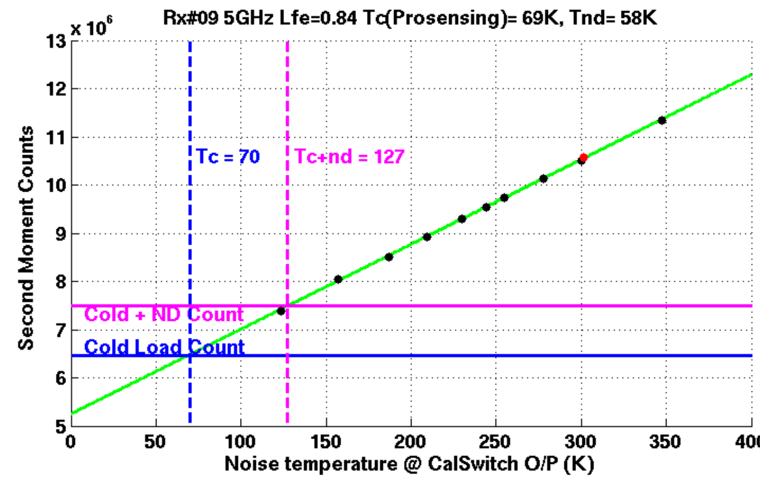
Final Tin_{CalSW} to Count Transfer Function

RECEIVER #09

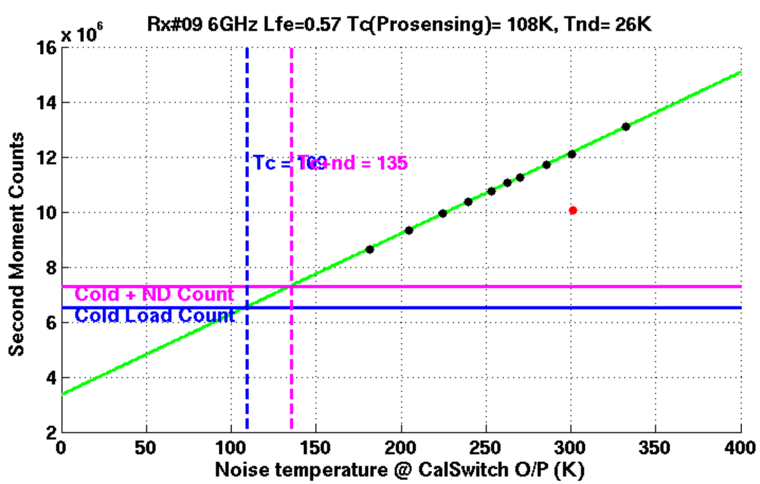
4.0 GHz



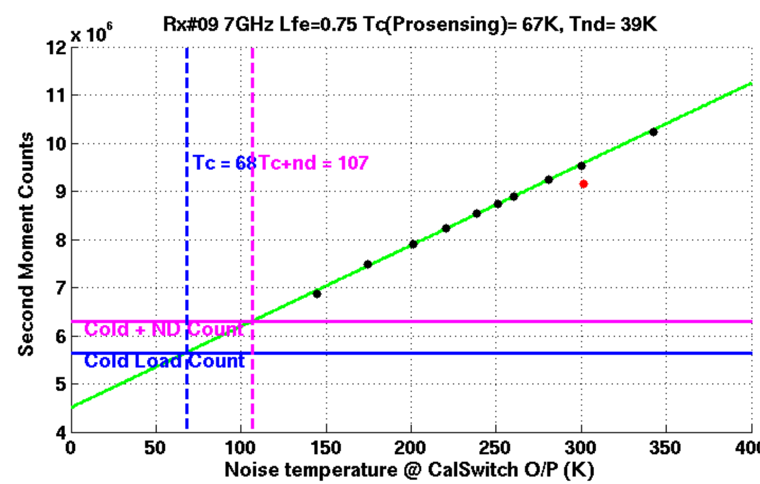
5.0 GHz



6.0 GHz

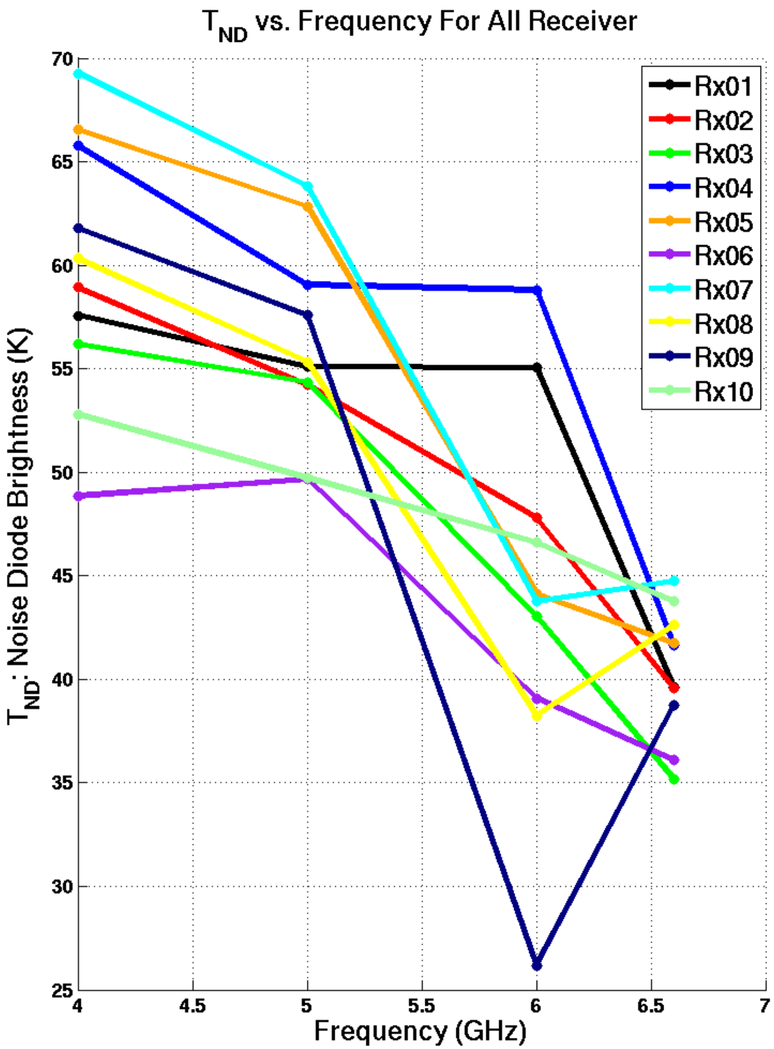


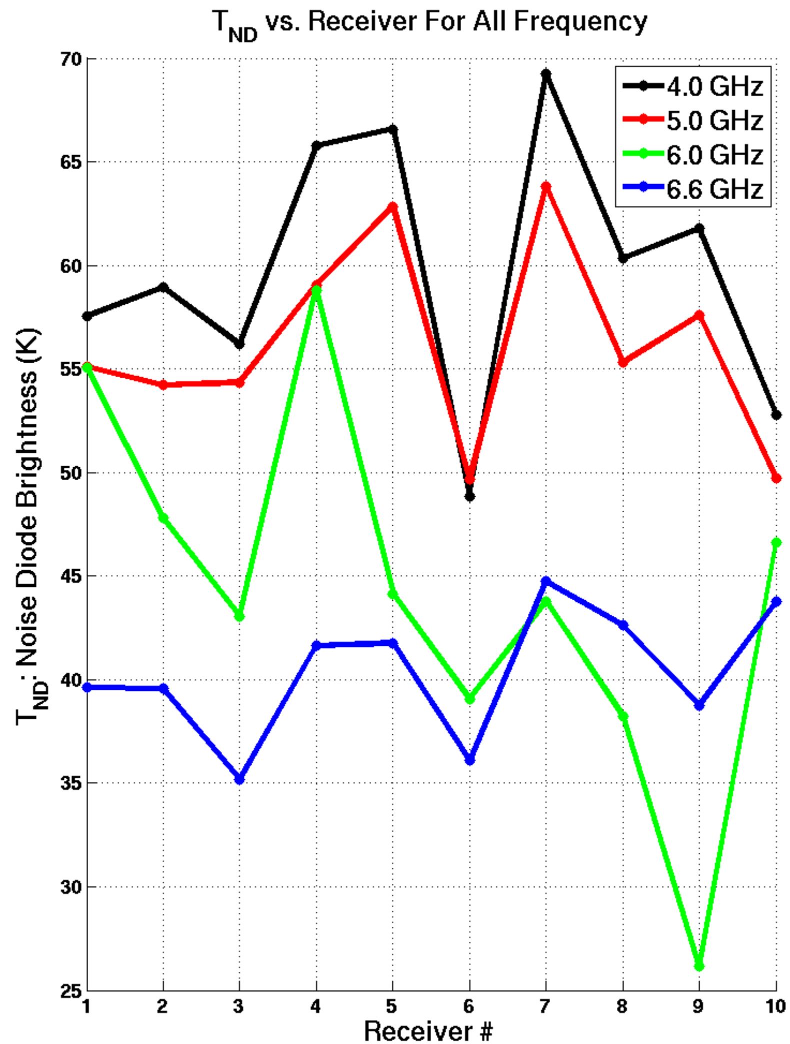
6.6 GHz



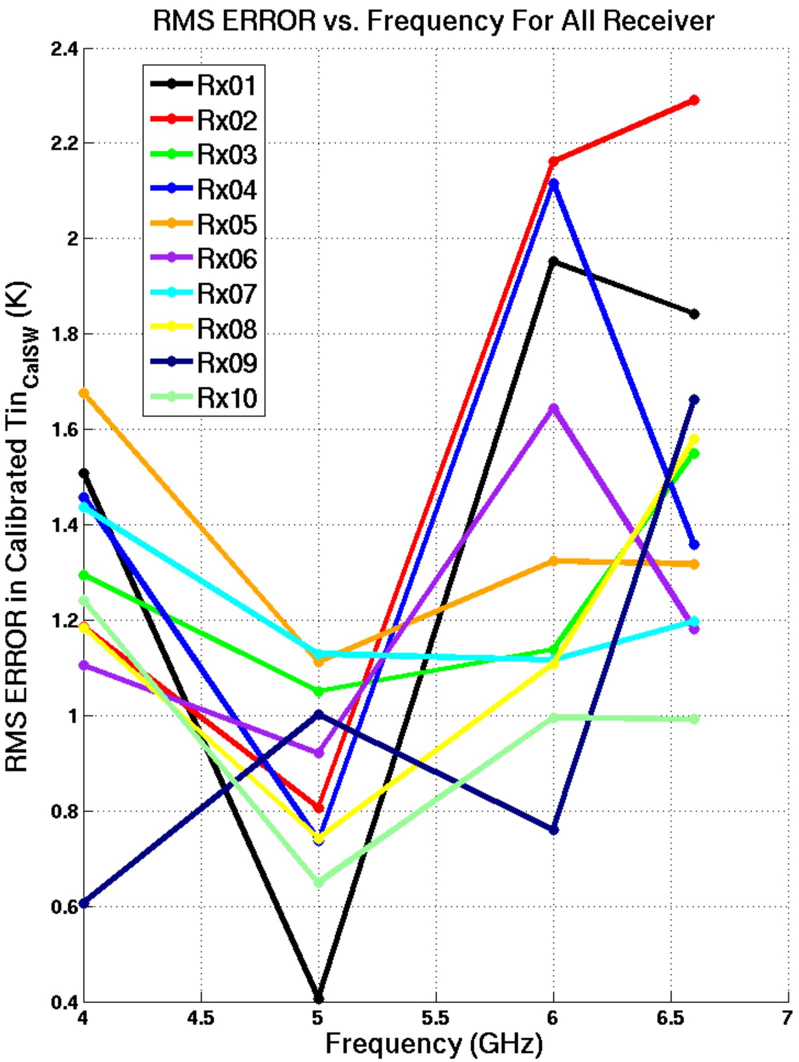
Solve Tnd using L_{fe} and Prosensing Tc

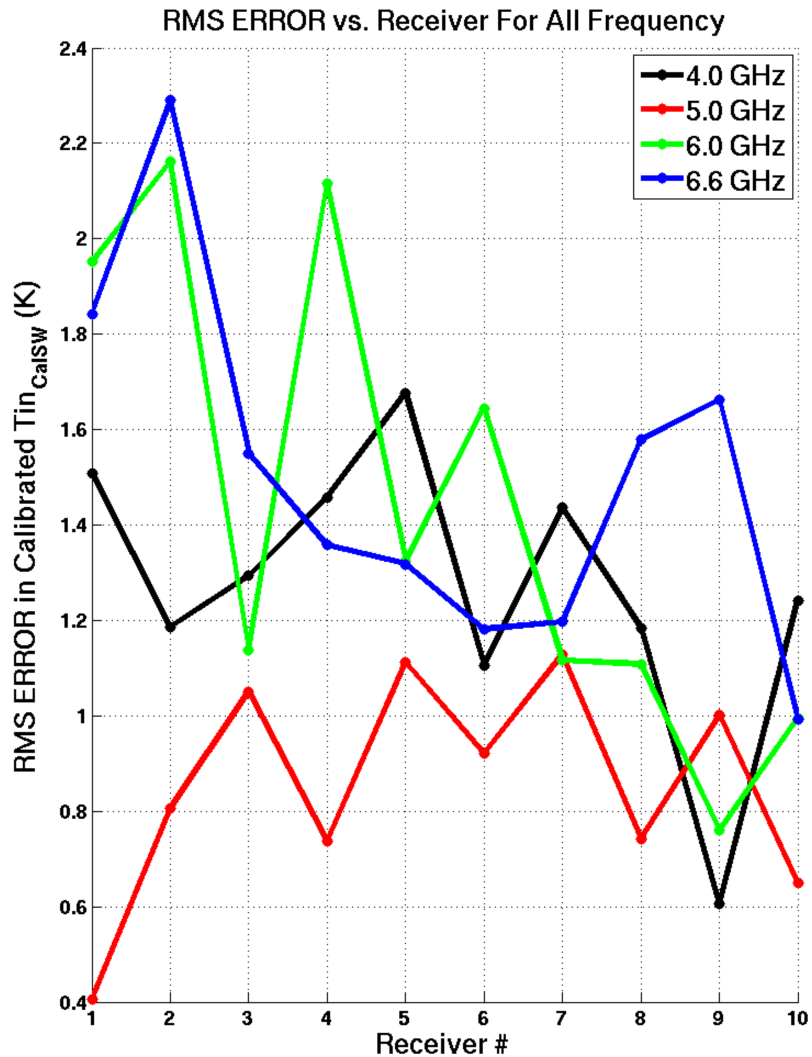
Estimated T_{ND}





RMS Uncertainties in Calibrated $\mathbf{Tin}_{\mathbf{CalSW}}$





Summary

- Laboratory calibration of HIRAD C-Band receivers is described: front-end loss and injected noise diode temperatures are estimated
- Internal warm load is excluded from current calibration
- RMS uncertainty in absolute calibration varies for receiver/frequency combinations between 0.4-2.3 K at the cal switch output reference.
- Current calibration produces ~ 4.7 ms-1 wind speed error based on estimates from ~600 dropsonde comparison.

Acknowledgement: *The authors wishe to thank L. Jones (University of Central Florida) whose MT7118J & MT7108B calibration loads were used for the test, C. Ruf (University of Michigan) for the valuable discussions during data analysis, C. Benson (NASA MSFC) and D. Simmons (University of Alabama), who procured the liquid nitrogen for this test and many other members of the HIRAD team who directly or indirectly helped in this work. This work was supported by the NASA Marshall Space Flight Center Earth Science Office and the NASA Hurricane and Severe Storm Sentinel (HS3) mission.*

BACK UP CHARTS

Lfe, Tc and Tnd Used in Final Calibration

Receiver#	LFE (ratio)				TC (K)				TND (K)			
	4 GHz	5 GHz	6 GHz	6.6 GHz	4 GHz	5 GHz	6 GHz	6.6 GHz	4 GHz	5 GHz	6 GHz	6.6 GHz
01	0.91	0.85	0.92	0.82	41	71	89	71	58	55	55	40
02	0.92	0.85	0.82	0.81	33	73	84	54	59	54	48	40
03	0.92	0.87	0.83	0.78	38	72	91	75	56	54	43	35
04	0.89	0.85	0.92	0.79	53	70	81	83	66	59	59	42
05	0.93	0.84	0.8	0.78	59	86	70	73	67	63	44	42
06	0.8	0.78	0.79	0.75	79	93	80	88	49	50	39	36
07	0.92	0.88	0.78	0.82	50	60	84	68	69	64	44	45
08	0.9	0.83	0.74	0.79	52	64	81	103	60	55	38	43
09	0.93	0.84	0.57	0.75	46	70	109	68	62	58	26	39
10	0.81	0.74	0.76	0.71	75	88	132	104	53	50	47	44

Subband Variation @ 6GHz (Rx#09)